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Driving the Phileas, a new automated public transport vehicle

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Abstract

Phileas is a high quality public transport vehicle combining characteristics of bus, tram, and the underground. Phileas is equipped with pneumatic tyres and complies with the statutory regulations for buses. Accordingly Phileas may drive everywhere on public roads where buses are allowed to drive. On dedicated lanes Phileas can also drive as a track vehicle and drive and stop automatically. This combination is new and as the dedicated lanes have level crossings with ordinary traffic this might have unexpected consequences in practice that must be studied in advance. For this reason 25 professional bus drivers have completed a number of experimental rides in a Phileas driving simulator. During these rides sometimes dangerous, and sometimes less dangerous, events happened that required active take-over of control by the driver. It was found that after the first experience with such a situation drivers always reclaimed control in time. It is advised to train the drivers on these situations, e.g. in a simulator, to avoid fatal consequences in real life first time encounters.

Keywords: Phileas, automated driving, automation, public transport, trust

Introduction

After being widely applied in aviation, automation is increasingly applied in surface transportation. The Automated Highway System, AHS (Congress, 1994), has been a large demonstration project to show that fully automated driving is feasible. Although completely automated driving is possible, most present applications aim at supporting the driver, or taking over part of the driver's task. Cruise control systems, e.g., were extended with "intelligence", so they would respond to slower driving cars ahead and adapt the speed of the vehicle (Hoedemaeker & Brookhuis, 1998).

In the USA in Minnesota public transport buses can drive on narrow emergency shoulders with aid of GPS and CCD camera line detection (Ward, Shankwitz, Gorgestani, Donath, De Waard, & Boer, this issue). Reason to implement these systems in public transport is in general to avoid congestion and to run service on time. In the Netherlands APTS (Advanced Public Transport Systems) developed a new vehicle, Phileas (Figure 1) that combines characteristics of a bus, a tram, and an underground. Average speed of most public transport vehicles is low as a result of stop time. Easy level entrance and exit of passengers dramatically increases operational speed as is shown by underground service. Phileas also docks at stops and has a level entrance/exit. As this manoeuvre is difficult to perform manually, in particular with the 24 metre double articulated vehicle, the action is completed automatically. A smooth docking manoeuvre is attained by mimicking the manoeuvre of a crab, Phileas has an all-wheel steering docking system and can drive and steer automatically on dedicated lanes equipped with magnets. At the same time the vehicle has the flexibility to leave this infrastructure and drive as a bus. The Phileas driver can switch from full automatic control ("underground") to semi-automatic control ("tram", i.e., longitudinal control operated by driver, lateral control by vehicle) to manual (like a bus). The driver is supposed to supervise the performance of Phileas when in (semi)automatic mode and can/should reclaim control if required. Phileas can only be under automated control if the vehicle is on a dedicated lane. These lanes will have level crossings with other traffic, while there is no headway radar on the Phileas that detects objects.

Key questions are whether drivers will trust Phileas, whether they actually will reclaim control if required, what driving mode they will prefer, and whether they accept automated driving. Studies performed in the Automatic Highway System have shown that drivers supervising the system very often do not reclaim control in critical situations (Desmond, Hancock, & Monette, 1998, De Waard, Van der Hulst, Hoedemaeker, & Brookhuis, 1999), while from a safety perspective this is crucial, in particular in a vehicle with up to 155 passengers.

Method

A mockup of the Phileas with original controls (pedals, instruments, steering wheel) was used for the experiment. An interface was developed and implemented for the University of Groningen driving simulator (Van Wolffelaar & Van Winsum, 1995) and (counter) forces on the steering wheel and

pedals were realistically simulated. When in automatic mode the steering wheel would move just like it moves in a real Phileas. A 18 metre articulated Phileas was simulated. The route that Phileas is going to drive in 2004 in Eindhoven was copied in terms of distance, curves, crossings (17 in total), speed limits (50 and 70 km/h), and number of stops. Driving the 9 km track in a single direction took 18 minutes, followed by 2 minutes resting time at the end point. Also included –corresponding to the real track– was a section without dedicated lane where Phileas always had to be driven manually. As a result control had to be handed over to Phileas at the beginning, and reclaimed at the end of the dedicated lane.



Figure 1. A picture of the 18 metre-Phileas

Participants in the experiment were recruited from two companies, from the Groningen local bus company (Arriva), and from the Eindhoven region (Hermes company), the potential future Phileas drivers. Arriva participants completed a total of eight rides; one ride to get used to the simulation, six rides that could be driven in automatic mode, and one ride that had to be completed in manual mode (order balanced over participants). Hermes drivers completed a total of three rides, one to get used to the vehicle and two automatic rides. During all automatic rides 30% of the route had to be driven manually (corresponding to the 2004 real situation), and drivers were stimulated to get experience with automatic driving, but could switch to semi-automatic or manual control if they preferred that.

Four critical scenarios that can be expected to occur in real life were developed to assess driver behaviour in these conditions:

1. A car blocking the dedicated lane at an intersection
2. A cyclist running a red light and crossing in front of Phileas
3. A cyclist crossing in front of Phileas while leaving a stop in automatic mode
4. A car driving illegally on the dedicated lane

These events happened during different rides at different locations.

The following driving measures were taken or derived:

- Percentage of the ride driven automatically, semi-automatically, and manually
- Minimum Time-To-Collision (TTC, Van der Horst 1990) in critical situations (as described above)
- Reaction time from a fixed moment (i.e., start of a scenario) to a response (i.e., pressing the brake more than 10% or taking over the steering wheel).

Acceptance of the Phileas was determined before and after the experiment using a standard questionnaire (Van der Laan et al., 1997). After the experiment trust in automation was assessed with a translated questionnaire specific to this subject (Jian, Bisantz, & Drury, 2000). After each ride the

drivers gave an overall rating of invested mental effort (Rating Scale Mental Effort, Zijlstra, 1993) and a self-rating of their driving quality (Brookhuis, De Vries, Prins van Wijgaarden, Veenstra, Hommes, Louwerens, & O'Hanlon, 1985). An evaluation of the dashboard and control interface concluded the experiment.

Participants from the local company (who had to participate in their own free time) were paid for their participation, participants from Hermes completed the rides during normal working hours and did not receive an additional payment.

Analyses

Hermes drivers completed two experimental rides, Arriva drivers seven. These drives were preceded by one test ride to get used to the vehicle. The following comparisons were made:

- Performance/rating first automatic ride versus second automatic ride (Arriva + Hermes)
- Performance/rating trend in automatic ride 1 to 6 (Arriva only)
- Average performance/ratings automatic ride versus manual drive (Arriva only)

Statistical analyses (mainly GLM, Repeated Measures Manova) were performed with SPSS.

Results

Participants

Results of the questionnaire survey are, if possible, based on a total of 29 participants (25 male); 13 drivers of Arriva, 16 of Hermes. Average age was 44 years (range 29-58), on average they worked 38 hours per week and total mileage varied between 15 000 and 2 500 000 km (average 500 000 km). Due to simulator sickness the vehicle measure data are based on a subgroup of 12 Arriva drivers and 13 Hermes drivers.

Mode of Driving

Drivers were encouraged to get experience with automated driving and drive as much as possible in that mode. However, if they preferred to drive manually or in semi-automatic mode, that was allowed. Thirty percent of the track had to be driven in manual mode (as that part contained no dedicated lanes). Although drivers drove slightly less (-1.5%) in automatic mode during the second ride, no trend over rides could be observed. On average 55% of the route was driven fully automatic, 7% semi-automatic ("tram") and 38% manually.

Effort

Ratings on the RSME (Zijlstra, 1993) showed that subjective mental effort declined over rides (square trend $F(1,10) = 8.10, p < 0.05$). Averages are shown in Figure 2, a score of 26 equals "some effort", a score of 58 "rather much effort". The difference between the automatic and manual rides did not reach the level of significance ($F(1,10) = 1.54, NS$).

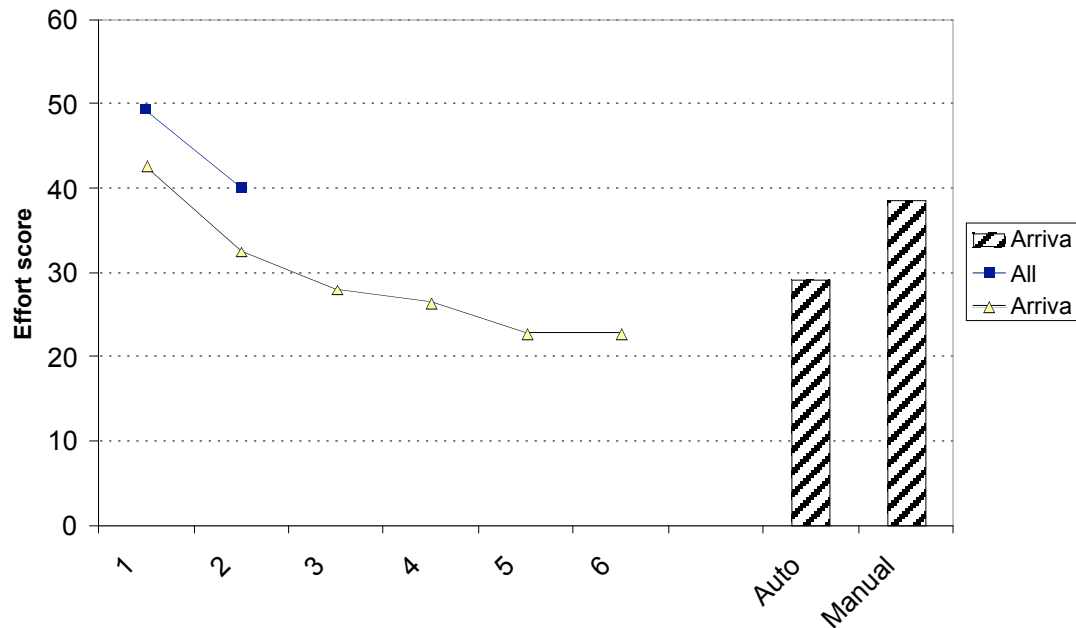


Figure 2. RSME (Effort) ratings per ride and the average rating for automatic and manual rides.

Rated Driving Quality

Over the drives the rated quality of performance increased ($F(1,10)=4.96, p < 0.05$). The manual ride was not judged to have been different from the automated rides.

Critical scenario 1: A car blocks the dedicated lane

The car blocking the intersection could be seen well in advance, and drivers braked and no accidents happened. Average minimal TTC in the first ride was 5.43 s, during the second ride 5.96 s. During the manual ride the minimal TTC dropped somewhat more, to 4.76 s ($F(1,10)=5.12, p < 0.05$), probably (also) related to an average 4.3 km/h higher driving speed while in that mode.

Critical scenario 2: A cyclist runs a red light

Seven times (28 %) the first encounter with this situation while driving in (semi) automatic mode ended with a collision. During the following rides only one collision happened. During the manual drives of the Arriva participants all stopped in time, with one exception. During the first encounter Phileas was in 80% of the conditions in automatic mode, in 12 % in semi-automatic and in 8% in manual mode. Reaction time followed a similar pattern.

Minimum TTC when excluding the collisions, as TTC becomes 0 in those conditions, was not different over rides. Average minimum TTC was 2.36 s.

Critical scenario 3: Phileas leaves a stop in automatic mode and a cyclist crosses the road in front of Phileas

In this condition just as many collisions as in Scenario 2 happened, 28% during the first encounter, during the second encounter (second ride) only once a collision occurred. Phileas was in 92% switched to automatic mode, in 4% to semi-automatic and 4% in manual mode. Again minimum TTCs of collisions were excluded and here also no difference in minimal TTC between the first and second ride was found (3.7 s.). Reaction time during the second ride was marginally faster, an average of 2.89 s opposed to 3.29 s during the first ride. Minimum TTC was *smaller* during the manual ride (2.27 vs. 3.43 s., $F(1,6)=13.12, p < 0.05$), probably as a result of braking hard in the automated condition as reaction time did not differ between conditions.

Critical scenario 4: A car is driving slowly and illegally on the dedicated lane

The car that was driving illegally on the dedicated lane was detected by all drivers and they all reclaimed control in time. Most responded by braking, some steered around the vehicle. TTC became marginally significantly smaller in manual mode (average 4.18 s.) opposed to 5.12 s in automatic mode ($F(1,8)= 4.63, p < 0.07$) while driving speed in that condition was 3.8 km/h higher. In other words, while driving automatically they drove faster but braked harder.

Questionnaires

The Acceptance Scale (Van der Laan et al., 1997) loads on two dimensions, a *usefulness* dimension and a *satisfying* dimension. Both scores have a range from -2 to +2. Acceptance was assessed before the experiment after Phileas had been described, and after experience with the system. Average scores are neutral to positive, in particular the Hermes drivers changed their opinion in the positive direction to the level of the Arriva drivers after they had experienced Phileas (Figure 3).

Trust in Phileas was assessed on the scale proposed by Jian et al. (2000). The trust scale has a range of -3 (absolutely no trust) to +3 (very high trust). Average score (+0.72) did not differ between the drivers of the two different companies.

Drivers were also asked what mode of driving they preferred and what aspects could or should be improved. The majority (93%) preferred automatic driving, only 7 % preferred the manual mode. For docking at a stop the full 100 % preferred the automatic mode. Comments with respect to the interface focussed on the driving mode not being clearly visible (it was indicated by two controls on the driver's left). Switching over by applying the brake was considered a good way by the majority (93%), take over by steering should be (and actually is) reserved for emergency situations.

Correlations

Whether drivers reclaim control early or (too) late is likely to be related to the extent to which they trust Phileas. Scores on the Trust Scale were related to Minimum TTC for the first and second automatic ride. As minimum TTC became zero in case of a collision, for Incident 2 these cases were excluded. Minimum TTC can be seen as a measure for "being out-of-the-loop". Results showed a significant relationship ($r = -0.50, p < 0.05$, one-tailed) between Trust and Minimum TTC. In other words, if trust is high, Minimum TTC becomes smaller as drivers reclaim control later. Trust and subjective ratings of Driving Quality also correlated ($r = +.40, p < 0.005$). Expectations about usefulness of the system (Usefulness dimension of the Acceptance Scale, Before -measurement) and Trust as assessed after experience with Phileas correlated positively ($r = +0.43, p < 0.05$). Contrary to expectations, Trust correlated negatively with the proportion of time drivers drove in Automatic Mode ($r = -0.37, p < 0.05$). Minimal TTC did not correlate with the Effort Rating, nor did minimal TTC correlate with the proportion of time driven automatically.

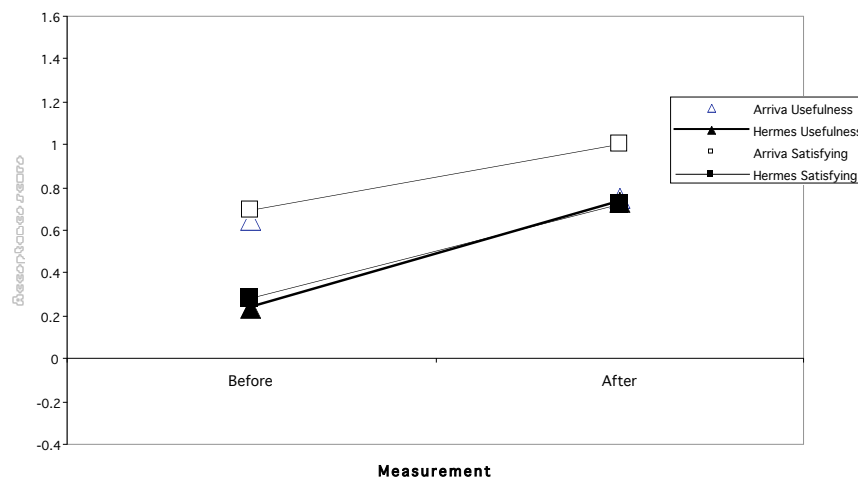


Figure 3. Scores on the acceptance scale (-2..+2), before and after experience with the Phileas simulation

Discussion and Conclusions

As Phileas has no frontal radar for obstacle detection the role of the driver remains crucial. When in (semi) automatic mode the driver has to remain alert for obstacles blocking the dedicated lane and for unexpected manoeuvres of other traffic participants. Key question in the present study was whether the driver remains "in-the-loop" when driving the Phileas in automatic mode.

Time critical events, such as the cyclist ignoring traffic rules and crossing unexpectedly close in front of Phileas were detected too late in 28% of the first time encounters. After this experience all critical situations were detected (with the exception of one, but that driver had also difficulty getting used to

the simulator), and the drivers responded in time. If time margins are ample such as in the condition where a car blocks the dedicated lane, all drivers reclaimed control well in time. Driver's opinion about Phileas was in general positive, and they trusted the automation. The correlation between the minimum TTC and the Trust score supports this. A negative relation between Trust and driving in automatic mode was found. Inspection of individual data showed that there were major differences between subjects, some showed a strong positive relation, others a negative (Fabriek, 2004). What causes these differences is at present unknown.

Training drivers on unexpected events is expected to facilitate take-over and avoid negative consequences of the first time encounter. It was also noted that some of the drivers developed a strategy of switching to semi-automatic mode when approaching an intersection. After having crossed the intersection they switched to full automatic mode again. This type of strategy could also be trained or implemented as it is very useful on locations where the chance of interaction with other (vulnerable) road users is high.

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